Watermark Detection Using Adaptive Color Projections

Field of the Invention:

The present invention relates to steganography and more particularly to the detection of watermark in multi-colored images.

Background of the Invention:

Techniques for embedding and detecting watermarks in colored images must take into account that each pixel is defined by a plurality of numbers representing different colors. For example each pixel may have a red, a green and a blue value. Luminance is a single value that can be calculated from the multiple values that define a pixel. A watermark can be embedded in an image by changing the luminance value of the pixels in the image. The luminance of a pixel can be changed by making changes along a particular color axis.

A widely used watermarking embedding technique examines the luminance values in an area surrounding a particular pixel to determine the amount of change in luminance that should be applied to that particular pixel. The watermark is embedded by changing the colors of each pixel along a vector from black to the color of the pixel. This technique can be termed "scale to black" watermark embedding.

A widely used watermark reading technique operates on detected changes in the luminance values of an image. A change in luminance is determined by projecting color changes onto a luminance axis. The change in luminance of each pixel is equal to the change in magnitude of a vector from black to the color of the pixel, projected onto the luminance axis.

Other watermarking embedding and reading techniques select a particular color plane of an image and imbed and read the watermark into and from that color plane.

1   Some systems that read watermarks apply a non linear filter to the image to obtain

2   a set of values from which the watermark (i.e. the grid signal or the data signals) is

3   read. A non-linear filter can, in effect, calculate a value for each pixel based upon

4   the value of the surrounding pixels. A variety of such non-linear filters have been

5   proposed. Some take into account the value of all adjacent pixels, others take into

6   account the value of the pixels on various axes such as the values on a set of cross

7   axes.

8

9   **Summary of the Present invention:**

10 The present invention provides a new image filtering technique that matches the

11 color axis of the watermark detector to the color direction used by the watermark

12 embedder. With the present invention, during the watermark reading operation, the

13 changes in the color values of each pixel <u>are not</u> projected onto a luminance axis or

14 onto a particular color axis. With the present invention, a preferred projection axis is

15 determined for each pixel. The preferred projection axis for each pixel

16 approximates the axis used to insert the watermark in that pixel. The preferred

17 projection axis does not necessarily coincide with the luminance axis or with the

18 axis of any other color component of the image. The preferred projection axis for

19 each pixel is determined by examining the color values in an area surrounding that

20 pixel. Once the preferred projection axis for a pixel is determined the color values

21 of that pixel are projected onto this axis to generate a set of values for the pixel.

22 The grid or data signal can then be detected from these values using known

23 techniques in the same way that a watermark can be read from the changes in

24 luminance values of an image.

25

26 A second embodiment of the invention inserts two watermarks in an image. The

27 two watermarks are inserted in orthogonal color directions. One of the watermarks

28 can be a fragile watermark. This technique can be used to detect if an image has

29 been duplicated.

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Brief Description of the Drawings:

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3 Figure 1 illustrates the pixels in an image.

4 Figure 2 illustrates the color vectors in a blue image printed with the conventional

5 CYMK colors.

6 Figure 3 is a block diagram showing the steps in a preferred embodiment.

7 Figure 4 illustrates use of the invention with two watermarks, one of which is a

8 fragile watermark.

9

Detailed Description:

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11 Digital color images generally consist of pixels or bits. The color of each pixel is

12 specified by specifying the values for a plurality of colors such as RGB (red green

13 blue), CYMK (cyan yellow magenta and black), etc. Figure 1 illustrates an image

14 that consists of pixels P_{11} to P_{xx}. Each pixel P_{11} to P_{xx} has an associated value for

15 each of the colors (RGB, CYMK, etc).

16

17 In order to better appreciate the present invention it is useful to first illustrate how

18 some existing watermark reading programs operate. When reading a watermark

19 some existing watermark reading programs calculate the change in luminance as

20 illustrated in Figure 2 and read the watermark from the calculated luminance

21 changes using a correlation process. Figure 2 illustrates a CYMK (cyan yellow

22 magenta black) image; however, the process is similar for other color

23 representations. The change in luminance of a pixel equals the change in

24 magnitude of a vector from black to the color of the pixel projected onto the

25 luminance axis. Figure 2 illustrates that for a blue pixel a change in the blue color

26 having a magnitude of the vector 201, results in a change in luminance equal to the

27 vector 202. The point which should be noted is that the magnitude of vector 202

28 (from which the watermark is detected) is smaller than the magnitude of vector 201.

29 If the image were an RGB image, the coordinates would be RGB instead of CYM,

30 but the process and the result would be the same.

1

2   In general the present invention is directed to matching the color direction of the

3   detection process to the color direction of the embedding process. This is

4   accomplished by filtering the image in such a manner that the detection process is

5   adaptive to the colors in the image.

6

7   The first embodiment of the invention described herein is directed to filtering an

8   image, which has been watermarked by using the "scale to black" watermarking

9   technique. The filtering provided by the present invention makes it easier to read

10   the watermark. Many commercial watermarking programs (such as the

11   watermarking program that is part of the Adobe Photoshop image editing program)

12   embed watermarks using the scale to black technique. In order to watermark an

13   image with the scale to black technique the particular change needed to insert a

14   desired watermark in each pixel is calculated. The watermark is inserted by

15   changing the colors of each pixel by, in effect, modifying a vector from black to the

16   color of the pixel by the particular percentage needed to insert the desired

17   watermark,

18

19   By filtering an image using the present invention, the ability to detect and read the

20   watermark using a correlation process is enhanced. In the particular embodiment

21   described herein, the color of each pixel is represented by the colors RGB;

22   however, it should be understood that the invention is equally applicable to images

23   represented by other colors.

24

25   Figure 3 shows the operations performed by a first embodiment of the invention. As

26   indicated by block 301, the process begins with a digital image that has been, for

27   example, created by scanning a watermarked physical image. The process is

28   directed to detecting a digital watermark in such a digital image. The digital image

29   consists of a plurality of pixels as indicated in Figure 1. There are three values for

1 each pixel representing the value of the RGB color components of the color of the

2 pixel.

3

4 As indicated by block 303, the "preferred projection axis" for each pixel is first

5 determined as hereinafter explained. A single value for each pixel is next calculated

6 by projecting the three color components of the pixel onto this axis. The calculated

7 single value for each pixel is next compared to the value of the surrounding pixels to

8 determine a projected value as indicated by block 309. Finally as indicated by block

9 311, correlation is used to detect and read the grid or watermark signal.

10

11 The calculation to determine the preferred projection axis will now be explained with

12 respect to pixel P_{45} shown in Figure 1. The value of the color components of pixel

13 P_{45} are designated R_{45} G_{45} B_{45}. First <u>average</u> values (designated aR_{45} aG_{45} aB_{45})

14 for the RGB colors in the nine pixel area surrounding P_{45} are calculated as follows:

15

16 $$aR_{45}\ aG_{45}\ aB_{45} \longrightarrow \sum_1^9 R \quad \sum_1^9 G \quad \sum_1^9 B$$

17

18 These values are made into a unit vector by dividing by the square root of the sum

19 of the squares of the values. The resulting unit vector designated r_{45} g_{45} b_{45} is the

20 preferred projection axis for that pixel.

21

22 The color values of the pixel P_{45} are next projected onto the preferred projection

23 axis by calculating the dot product of the two vectors as follows:

24 $$<r_{45}\ g_{45}\ b_{45}> \bullet\ < R_{45}\ G_{45}\ B_{45}>$$

25

26 The above calculation is done for each pixel in the image. The result is a set of

27 values that can be used to first detect a grid signal. The image would then be

28 scaled and oriented as appropriate and the above calculations would again be

29 made and a watermark data detection algorithm applied. It is noted that the values

30 calculated as described above, could be first be used to detect the grid signal, and

1   then after the image is oriented, the same values (in a re-oriented location) could be

2   used to detect the watermark data signal.

3

4   While the embodiment described above calculated the average values over a nine-

5   pixel area, it is noted that in alternative embodiments the image is calculated over

6   other size areas. For example the average could be calculated over a 100 by 100

7   pixel area or even over a larger area.

8

9   The correlation process to detect and read the grid and watermark data signals

10   does not form a part of the present invention. Various techniques can be used to

11   perform the detection and reading operation. For example, the watermark detection

12   and reading process can be performed by watermark reading techniques described

13   in publicly available literature or by the techniques described in co-pending

14   applications 09/186,962, filed November 5, 1998, or in co-pending application

15   09/503,881 filed 02/14/2000. The above referenced co-pending applications are

16   hereby incorporated herein by reference.

17

18   Figure 2 illustrates, as an example, a pure blue image printed using the

19   conventional CYMK colors.   Figure 2 illustrates that when a watermark is

20   embedded by a change in the luminance value reflecting a change in the color blue

21   of a CYMK image, the watermark is predominantly in the yellow color. That is, with

22   a blue image, indicated by the vector 201, a change in luminance indicated by the

23   vector 202 will be primarily be reflected by changes in the yellow color 203.

24

25   With the present invention, the detector will automatically look for the watermark

26   primarily in blue color direction as a result of calculating color channel weights as

27   follows.

28

29   red_wt = red_ave / (red_ave + green_ave + blue_ave)
30   green_wt = green_ave / (red_ave + green_ave + blue_ave)
31   blue_wt = blue_ave / (red_ave + green_ave + blue_ave)

32

In a blue area, red_ave = 0, green_ave = 0, and blue_ave = 255 i.e. red_wt = 0, green_wt =0 and blue_wt = 1. These values are used to weight the red, green and blue pixel values in a pixel block of a selected size (e.g. 3 by 3, 100 by 100, etc.) to create a single weighted average channel, which is used for watermark detection. Thus with the present invention the full blue change is seen by the detector.

The following illustrates what occurs if a watermark detection is done in the luminance channel instead of using the present invention. Luminance is conventionally calculated as follows:

$$\text{Luminance} = 0.3*\text{Red} + 0.6*\text{Green} + 0.1*\text{Blue}$$

With the image illustrated in Figure 2, if detection were done in the luminance channel a much smaller change would be detected. For example a change of 20 in blue would become a luminance change of 2.

It is also noted that by matching the color direction of the detector to the color direction used by the embedder, image noise that would otherwise interfere with the detector is effectively rejected. For example, in the example of a blue image given above any image data in the red and green channels would not interfere with the watermark in the blue channel.

To obtain the maximum benefit from the adaptive color detection, the camera color reproduction should be made as accurate as possible. Standard tools are available for achieving this, such as using ICC color profiles for the camera. For best results, a camera should be individually characterized, or less accurately a generic profile for the camera type can be used. An individual camera is characterized by reading a printed target with known color values. The target values are used to calculate the required color transformation to achieve the expected output values.

1 The size of the area over which the colors are averaged can range from a 3 by 3
2 area to an area multiple hundred pixels square. A small area will involve more
3 computation time; however, it will generally provide better results for images that
4 have color areas of smaller size. Watermarking programs generally insert
5 watermarks several times in an image. The size of the area in which the watermark
6 is inserted is sometimes referred to as the tile size. Averaging over an area the size
7 of the watermark tile provides an advantage in that the detector program is
8 configured to operate on pixel areas of this size.
9
10 An alternate embodiment of the invention which utilizes two watermarks designated
11 Mark 1 and Mark 2 is illustrated in Figure 4. The second watermark, mark 2, has a
12 lower intensity or strength than the first watermark, Mark 1. The lower strength
13 makes it difficult to copy Mark 2 by scanning or photocopying the image. In order to
14 keep the second watermark, mark 2, from interfering with the first watermark, mark
15 2 is inserted in a color space orthogonal to the first mark.
16
17 Figure 4 illustrates an example of the color directions of the two watermarks. Mark
18 1 is inserted using a conventional "scale to black" technique. Hence for a blue color
19 this can be represented as a change in the direction of the vector A designated 401.
20 The second watermark is inserted in an orthogonal direction as indicated by the
21 vector 402. In figure 4 the luminance axis is designated as vector B. The direction
22 (designated "V") of the second water mark can be defined as the cross product of
23 vector A and vector B. That is:
24 $V = A \wedge B$
25
26 To help distinguish between the two watermarks, the second watermark can also
27 have a different resolution from mark 1. For example mark 1 could be at 75 lpi and
28 mark 2 at 300 lpi.
29

1   The first watermark is applied in the same manner as described above relative to

2   the first embodiment. That is, the change needed to embed the first watermark is

3   calculated by in effect scaling by an appropriate amount a vector between black and

4   the color being changed.

5

6   The second watermark (i.e. the fragile watermark) is applied, by calculating a color

7   change perpendicular to the direction of the first watermark. The perpendicular

8   color vector (designated V) is calculated by calculating the cross product of vector A

9   and vector B as indicated above. The fragile watermark is applied by scaling the

10   vector V in the same way that the first watermark was applied by scaling a vector

11   from black to the color.

12

13   In this example, the detector would first look for watermark 1 in the blue direction,

14   and then for authentication look in the red direction. Mark 2 can have a much

15   smaller payload, since it is only used to verify that mark 1 is valid. Such a scheme

16   would also help diminishes the chances that an attacker can successfully recover

17   the watermark signal from an image and embed it in another image in a manner that

18   enables an accurate decoding of the watermark in the other image. This is the case

19   since the 2 watermarks would be dependent upon the underlying image content. An

20   attack which high pass filters an image and adds this signal to image 2, copies the

21   watermark in a manner which is independent of image content, and would therefore

22   probably fail an authentication step.

23

24   While the specific embodiments described herein relate to watermarks in a spatial

25   domain with a particular form of scaling in the color space, the invention can also be

26   used with other watermarking techniques such as those that make changes in the

27   direction of other color vectors in a color space. In such an embodiment, the

28   detector would project to a vector in a direction corresponding to the direction of the

29   embedder.

30

1   It is also noted that there are numerous transform domains, including DCT, wavelet,

2   Fourier, Hough, Karhunen Loeve, Haar, Hadamard, Radon, etc. etc. Color specific

3   watermark embedding and detection can be implemented in these transform

4   domains by dividing the image into blocks, transforming the blocks into desired

5   color space (if not already represented in that space), transforming blocks into

6   transform domain, modify transform coefficients according to some embedding

7   function (which may be a linear or non-linear function of the transform coefficients),

8   then inverse transform the modified data to get the watermarked image. Some

9   other approaches make a calculation to get the watermark signal, then inverse

10   transform the watermark signal to the spatial domain, and finally add the spatial

11   domain watermark signal to the original host signal.

12

13   In such systems with the present invention the watermark decoder makes a color

14   analysis (on a region by region basis, where the region can be of varying size as

15   previously noted) to determine from which color space to decode the watermark,

16   and then transforms the data to that space, transforms into the transform domain

17   where the watermark signal was embedded, and applies a decode operation

18   compatible with the embed operation (such as correlation, statistical feature

19   calculation, quantization, statistical probability measure, etc.).

20

21   While the invention has been shown and described with respect to preferred

22   embodiments of the invention, it should be understood that various changes in form

23   and detail could be made without departing from the spirit and scope of the

24   invention. The invention is limited only by the appended claims and equivalents

25   thereto.

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28   I claim:

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